Sensitivity of Heavy Precipitation Forecasts to Small Modifications of Large-Scale Weather Patterns for the Elbe River

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ABSTRACT

Extreme flood events are caused by long-lasting and/or intensive precipitation. The detailed knowledge of the distribution, intensity, and spatiotemporal variability of precipitation is, therefore, a prerequisite for hydrological flood modeling and flood risk management. For hydrological modeling, temporal and spatial high-resolution precipitation data can be provided by meteorological models. This study deals with the question of how small changes in the synoptic situation affect the characteristics of extreme forecasts. For that purpose, two historic extreme precipitation events were hindcasted using the Consortium for Small Scale Modeling (COSMO) model of the German Weather Service (DWD) with different grid resolutions (28, 7, and 2.8 km), where the domains with finer resolutions were nested into the ones with coarser resolution. The results show that the model is capable of simulating such extreme precipitation events in a satisfactory way. To assess the impact of small changes in the synoptic situations on extreme precipitation events, the large-scale atmospheric fields were shifted to north, south, east, and west with respect to the orography by about 28 and 56 km, respectively, in one series of runs while in another series, the relative humidity and temperature were increased to modify the amount of precipitable water. Both series were performed for the Elbe flood events in August 2002 and January 2003, corresponding to two very different synoptic situations. The results show that the modeled precipitation can be quite sensitive to small changes of the synoptic situation with changes in the order of 20% for the maximum daily precipitation and that the types of synoptic situations play an important role. While van Bebber weather conditions, of Mediterranean origin, were quite sensitive to modifications, more homogeneous weather patterns were less sensitive.

1. Introduction

The detailed knowledge of the spatiotemporal distribution, intensity, and variability of precipitation is a fundamental prerequisite for hydrological flood modeling, design of flood protection dykes and retention basins, and operational flood risk management. For such purposes, temporal and spatial high-resolution precipitation data are provided by meteorological models, where all meteorological scales from large to regional and local (catchments of small rivers) are considered simultaneously.

For planning purposes that are based on, for example, statistics of threshold values or return times of events, but also before and during intense precipitation events, it is important to know how precipitation intensity can vary when certain inherent uncertainties are considered. Depending on the kind of event (frontal, convective, among others), the rainfall duration and intensity depend on the properties of the air masses (e.g., temperature and amount of precipitable water), and also on the trajectories and position of the synoptic patterns relative to orography and land use. It can be expected that synoptic situations with strong gradients in pressure or air-mass properties are especially sensitive to position and trajectory deviations when interacting with complex terrain. The interaction between orography and stratiform precipitation has been studied by Kunz and Kottmeier (2006a, 2006b) within the priority program “Quantitative Precipitation Forecast” [Special Priority Program (SPP) 1167] of the German Research Foundation [Deutsche Forschungsgemeinschaft (DFG); Hense and Wulfmeyer 2008] and within the Convective and Orographically

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Induced Precipitation Study (COPS; Wulfmeyer et al. 2003; Kottmeier et al. 2008).

Although knowledge of the modeled precipitation variability is quite important, literature on this topic is quite scarce. Amengual et al. (2007) used an ensemble of the fifth-generation Pennsylvania State University–National Center for Atmospheric Research Mesoscale Model, version 5 (MM5) simulations with small shifts (±54 km) and variations of intensity (±5% potential vorticity) of the precursor upper-level synoptic-scale trough to assess the effects on the hydrological response of relatively moderate spatial and temporal errors of the forecast rainfall field. While one half of the perturbed simulations were fairly similar to the observed rainfall pattern, the other half revealed spatial errors that were greater than those observed in the reference experiment. Modification of the potential vorticity is a common way to perturb the atmospheric fields. Manders et al. (2007) used this method to modify numerical weather forecasts to assess numerical errors within forecasts.

There are several model-based possibilities to assess the variability of the intensity of extreme precipitation events. One possibility is to perform ensemble simulations with nested global–regional models and to analyze the resulting bandwidth of precipitation in the region of interest. The Limited-Area Ensemble Prediction System (LEPS) (Marsigli et al. 2005) developed by the Consortium for Small Scale Modeling (COSMO-LEPS) is used, for example, by the Swiss weather service MeteoSwiss to issue daily probabilistic operational forecasts of rain, snow, and wind for Switzerland and the alpine region (available online at https://shop.meteoswiss.ch). This approach can be applied to events of the recent past, but not to cases further back in the past, because global ensemble data is not available for earlier events. In such cases, one possibility is to modify existing large-scale forecasts within physically reasonable limits and to study the impact of such modifications on regional forecasts. This can be done by changing the properties of the air masses involved and/or by shifting the air masses relative to the underlying orography. Variability is measured as the deviation due to such modifications from a reference run, selected as the run which reproduces the observed precipitation as faithfully as possible.

For hindcasts of recent events, reanalyses from global models such as the Global Model (GME), Integrated Forecast System (IFS), or 40-yr European Centre for Medium-Range Weather Forecasts Re-Analysis (ERA-40) are available to provide input data for a regional model. In the study presented here, the positions of the synoptic patterns were shifted north, east, south, and west with respect to the orography by one or two grid boxes to evaluate the variability of precipitation. As to the second possibility, temperature and humidity fields, modified in a physically consistent way, were used as initial and boundary data. This should simulate a warmer/cooler and moister/drier atmosphere, respectively.

These approaches and the effects of these modifications on the precipitation fields will be discussed in this paper. They have been applied to the Elbe River flood events of August 2002 and January 2003 in eastern Germany using the COSMO model of the German Weather Service (DWD).

The next section describes the model domain and the selected events. The model and the methodology used for these evaluations, are discussed in section 3. The results are presented in section 4. Section 5 is dedicated to the conclusions.

2. Model domain and selection of cases

a. Model domain

Within this project recent flood events of the middle Elbe River were considered. To simulate discharges in hydrological modeling, precipitation data for the whole catchment area of the upper and middle Elbe River, which was severely damaged during the flood events mentioned in section 2b, was required. The catchment area includes parts of the Czech Republic, where the catchment area is surrounded by the Giant Mountains, Eagle Mountains, the Bohemian–Moravian Highlands, which are the main water divide between the Elbe River and the Danube; the low mountain range of the Bohemian Forest; the Upper Palatinate Forest and the Ore Mountains; and parts of eastern Germany. The model domains are shown in Fig. 1. While a coarse model grid with 28-km grid spacing for central Europe was used to create initial and boundary data of the reference run and of the scenarios, a smaller grid with 7-km grid spacing was nested into the coarser grid to simulate the precipitation fields, which were required for subsequent hydrological modeling. Detailed information about the methods can be found in section 3b.

b. Description of the selected cases

Flood events were grouped according to their initiating weather conditions to ensure the comparability of the model results. Four basic types of weather conditions were identified, and model studies were prepared for each of them (Table 1)—that is, for winter events with mainly pluvial characteristics (type W1); winter events with a significant fraction of snowmelt (type W2); summer events with Vb patterns (van Bebber 1898) and similar atmospheric circulation patterns (type S1); and summer events characterized by persistent cyclonic westerly flow (type S2). In this paper, two flood events of
type S1 and W1 will be discussed. The synoptic situations and the results of the model simulations are described in section 4.

3. Model and methods

a. Model

The study was conducted using the COSMO model, version 4.0, which was derived from the operational weather forecasting model of the DWD. The COSMO model was developed by the Consortium for Small Scale Modeling. It is nonhydrostatic and uses a rotated grid to minimize computational errors due to nonparallel longitudes. More details on this model can be found in Steppeler et al. (2002, 2003) and Doms and Schättler (1999). A detailed description of the COSMO model and its dynamical and physical core can be found in Rockel et al. (2008). The model grid of the coarse model domain covered central Europe (Fig. 1) and had 70 × 60 grid points with 35 vertical levels and a horizontal resolution of 0.25°, which corresponds to ~28 km grid spacing. In the following, it will be referred to as the coarse nest. Global analysis data from the GME model, which were available every 6 h, served as boundary and initial data for the coarse nest. The results of the coarse nest runs served as boundary data for one-way nested model simulations with 90 × 75 grid points, 35 levels, and a horizontal resolution of 0.0625°, which corresponds to ~7 km and will be referred to as the fine nest. The time step was set to 40 s in both model runs. Convection was parameterized in both nests using the Tiedke convection scheme. For investigation of still higher-resolution model simulations, an additional nested model run with 0.025° horizontal grid spacing (~2.8 km) was performed with 161 × 161 grid points, 50 levels, and a time step of 30 s. In this case, the Tiedke convection scheme was switched off, but a parameterization for shallow convection was used nevertheless. In this model run, a different prognostic scheme was applied: while the coarse and fine nest runs used the three-time-level leapfrog scheme, the 2.8-km run used the two-time-level Runge–Kutta timesplit scheme; this corresponds to the settings of the operational model system COSMO-DE at DWD. Unless stated otherwise, all subsequent analyses will be based on the fine nest runs.

Sensitivity studies were conducted to obtain the best model configuration. These studies included different model domains (with the Alps included or not), different nesting methods, different initial and boundary data, and changes in time step and orographic filtering. The

| TABLE 1. Classification of flood events according to the corresponding synoptic situation. |
|---------------------------------|----------------|----------------|
| **Summer events due to**        | **Winter events with** |
| S1 Vb patterns and similar circulation patterns | W1 Predominant pluvial characteristics |
| S2 Persistent cyclonic westerly flow | W2 Significant fraction of snowmelt |
results have shown that the operational configuration of the COSMO model at DWD agrees best with the measurements described in section 3c. Sensitivity with respect to initial and boundary data for the Elbe flood case was also studied by Zängl et al. (2006).

b. Methods

To estimate the precipitation that could occur if the large-scale synoptic situation was slightly modified, all atmospheric fields were shifted in the coarse model domain to north, south, east, and west with respect to the orography by 28 and 56 km, corresponding to one and two grid boxes of the coarse model domain, respectively. This shifting is intended to capture the position uncertainty of modeled synoptic systems relative to the earth's surface due to low model resolution. In this paper, we will focus on the regional effects of this uncertainty induced by low large-scale model resolution, although low resolution limits large-scale weather model accuracy in several other ways (Rudolf and Rapp 2003). Since precipitation is in many cases (and certainly in the August 2002 case) triggered by the interaction of air masses with orography, changing the relative positions may have a considerable impact on precipitation amounts and positions. The considerable variability of the paths of cyclones—as described, for example, in James et al. (2004) and Seibert et al. (2007)—can also be attributed partly to this position uncertainty.

The constant and the ground-based fields, such as soil temperature or soil moisture, were not shifted to avoid inconsistencies with respect to orography and soil inventory; this introduces an initial misfit between the atmospheric and surface fields. We deemed this inconsistency to be acceptable for the following three reasons: (i) a certain amount of inconsistency is unavoidable when coupling weather forecast models that differ in resolution, physics, parameters, and inventories (orography, soil, land use); (ii) owing to precipitation, soil moisture is close to saturation, therefore we expect that the atmosphere and the upper soil layers will reach a dynamic equilibrium after a short spinup time; and (iii) part of the inconsistencies is absorbed by the coarse nest. During the coarse nest runs (resolution 28 km), unbalanced atmospheric fields at the boundaries were quickly balanced by the model (Fig. 2) so that the results could be used as shifted and balanced boundary data inputs for the fine nest runs at 6-h intervals; in this way, good model stability could be ensured. The resulting fine nest precipitation fields will be discussed in the following section.

In our second approach, the properties of the initial and boundary fields for the coarse nest runs were modified, and the results of the completed runs were used as input for the fine nest runs. In a first set of simulations, the relative humidity was increased by 5%, 10%, 15%, and 20%, respectively, with the upper limit being 100%. This increased the specific humidity because temperature was kept constant. In a second set of simulations, the temperature was increased in four steps (0.5, 1, 1.5, and 2 K, respectively) while the relative humidity was kept constant. This resulted in an increase in specific humidity. The relative humidity and temperature were reduced in the same way. The relationship between specific humidity and temperature is controlled by the nonlinear Clausius–Clapeyron relation. Schär et al. (1996) and Frei et al. (1998) estimated an increase of 15% to 16% in specific water content by a temperature increase of 2 K. A complete list of the modeled scenarios and a description of each abbreviation is given in Table 2.

c. Data

Daily precipitation sums from more than 1600 stations in Germany and the Czech Republic were available for comparison with the simulations. This large amount of stations ensured a very good coverage with measurements. Hourly precipitation sums were also available, but the number of stations was less and, most importantly, part of the data (especially in the Czech Republic) was not corrected for undercatch, leading to a strong underestimation of the actual precipitation. Therefore, these observations were not used for the evaluation of the model data.

Rain gauges are generally considered to provide the most accurate observations of precipitation (Ebert et al. 2003a,b). Therefore, no other observations, such as radar or satellite measurements, were used. The precipitation measurements of the rain gauges were then interpolated to the model grid using the Kriging method for comparison with the model grid output.
4. Results

The flood events in August 2002 and January 2003, representing different types of synoptic weather conditions (types S1 and W1, respectively), were investigated.

a. Case 1: Flood event in August 2002, type S1

1) SYNOPTIC SITUATION

According to the classification by Hess and Brezowsky (Gerstengarbe and Werner 2005), the general weather situation was characterized by a depression [Tief Mitteleuropa (TM), low over central Europe] following a trough over central Europe [Trog Mitteleuropa (TRM), trough over central Europe]. Two successive extreme precipitation events at the beginning of August 2002 led to disastrous flooding in Germany, Austria, and the Czech Republic. During the period 6–7 August, widespread and heavy precipitation struck east Bavaria, Bohemia, and Austria due to a depression that carried warm and humid air masses from the Mediterranean Sea over the Alps to Hungary and the Black Sea coast. Some stations reported precipitation >100 mm within 48 h. During the period 10–13 August 2002, the next trough with a center over the northern Mediterranean Sea moved eastward. At the surface, a low pressure system moved from the Gulf of Genoa around the eastern Alps to eastern Germany, remaining there for a few hours, and then moved eastward to the Ukraine on 13 August. This route is well known as a Vb pattern (van Bebber 1898), which often advects humid air masses that lead to heavy precipitation and sometimes flooding (Mudelsee et al. 2004). During the first period of the event, precipitation was concentrated in the area of the Alps, but from 11 August onward expanded to the Czech Republic and eastern Germany. The warm and very humid air masses caused extraordinary amounts of precipitation for this region. Especially on 12 August, several stations reported 50–100 mm rain within 12 h. The largest amount was reported to have been 313 mm within 24 h at the Zinnwald–Georgenfeld site in the Ore Mountains near the German–Czech border. More details about this event can be found in Rudolf and Rapp (2003).

2) VALIDATION

The simulations (28 km, 7 km, and 2.8 km) started at 0000 UTC 6 August 2002 and terminated at 0600 UTC 14 August 2002. The first 6 h were not taken into account for evaluation, allowing the model a spinup time before onset of precipitation; thus, the model results were available for a full eight days. The fine nest simulation in the reference setup without modifications is referred to as the reference run in the following. The result of the precipitation sum for the overall period is shown in Fig. 3. The modeled precipitation maxima had the right magnitude, and the spatial distribution of precipitation agreed well with the observations, the highest amounts occurring in the vicinity of mountain ranges. The model simulations had a correlation coefficient of 0.78, which is a good score for precipitation modeling. The domain-averaged daily precipitation sums could be hindcasted in a satisfactory way as well (Fig. 4, left). Both the reference run and model simulation with 2.8-km grid spacing agreed well with the measurements, despite the underestimation of the maximum on 12 August. The observed 24-h precipitation sums show a bimodal distribution, which could not be reproduced by the model simulations (Fig. 4, right). During such extreme events, however, observation data uncertainty can be quite high because the probability of registering the precipitation maxima of convective events at a rain gauge station is quite low, and the spatial distribution of precipitation disagreed with the measurements, despite the model simulations had a correlation coefficient of 0.78, which is a good score for precipitation modeling. The domain-averaged daily precipitation sums could be hindcasted in a satisfactory way as well (Fig. 4, left). Both the reference run and model simulation with 2.8-km grid spacing agreed well with the measurements, despite the underestimation of the maximum on 12 August. The observed 24-h precipitation sums show a bimodal distribution, which could not be reproduced by the model simulations (Fig. 4, right). During such extreme events, however, observation data uncertainty can be quite high because the probability of registering the precipitation maxima of convective events at a rain gauge station is near 1% (Rudolf and Malitz 2008). With these caveats, we can state that the model setup reproduced this extreme precipitation event in an acceptable way.

A further refinement of the grid spacing down to 2.8 km and the use of COSMO-DE did not increase the model skill. We suspect that the model domain may have been too small, so the higher resolution of 2.8 km could not take advantage of better orography resolution. Instead, all local maxima were reduced quite systematically. It seems that the deactivation of the convection scheme
results in less precipitation, although convection should be resolved explicitly on that scale and shallow convection was still parameterized. In contrast, Zängl (2004, 2007), using the MM5 model, reported that the refinement of the grid spacing from 9 km down to 1 km had a highly beneficial effect in the alpine region, but not all of his selected cases showed these improvements.

3) SHIFTING AGAINST OROGRAPHY

For evaluation of the variability of the precipitation, the results of shifting (the synoptic pattern) relative the orography are shown in Fig. 5. While the simulations with shifted input fields showed a high variability on 7 and 11 August 2002, the maximum on 12 August did not vary much (Fig. 5, left). It can be seen that some of the shifted events produced higher precipitation than the real event, and that the observed local precipitation maximum around 7 August appears in all shifted simulations except e2. Nearly all simulations produced higher maxima, so we can conclude that the precipitation amounts could have been higher within the positional uncertainty range of the large-scale model.

The sums of the averaged precipitation differences demonstrated the dependency on the shifting. While

![Figure 3](image1.png)

**Fig. 3.** (left) The observations of the precipitation sum of the overall period (6–13 Aug 2002) and (right) the model result of the reference run. The correlation coefficient over all grid cells is $r = 0.78$.

![Figure 4](image2.png)

**Fig. 4.** Time series of the domain-averaged daily precipitation sum of the measurements and the two model runs with (left) 7-km and 2.8-km grid spacing for the 2002 Elbe flooding and (right) the frequency distribution of the 24-h precipitation. TM (TRM) means low (trough) over central Europe.
shifting to the north (n1 and n2) increases precipitation, the precipitation with a shifting to the east (e1 and e2) was less with respect to the reference run. In three of four cases, shifting by 56 km resulted in a larger change of precipitation than shifting by 28 km (Fig. 5, right). The spatial distributions of the precipitation pattern were not shifted in the same direction as the shifting of the large-scale weather situation, although the largest amounts of precipitation could still be found over, or in the vicinity of, the major mountain ranges. On smaller scales, however, the patterns differed considerably since shifting implied changes in pressure, wind, and moisture distributions and, consequently, different interactions with the orography.

4) MODIFIED TEMPERATURE AND HUMIDITY FIELDS

The scenarios with modified specific humidity have shown distinct changes in the resulting precipitation pattern. As can be expected, the amount of precipitation decreases when specific humidity decreases and increases rapidly when specific humidity increases (Fig. 6, top left and right). The spatial distribution also differed to some extent, but the precipitation maxima over the Ore Mountains and the southern Elbe catchment area remained unchanged. Times of high variability were essentially limited to 7 and 11 August, similar to the sensitivity of the scenarios with shifted atmospheric fields (Fig. 5, left). The overall precipitation sum did not increase further after increasing more than 10% in relative humidity because of the limitation of relative humidity to 100%.

On 7 August, increasing temperature resulted in much more precipitation, while decreasing temperature had no significant effect (Fig. 6, bottom left). The sensitivity on 11 August is similar to the sensitivity of changes in relative humidity. Both increasing and decreasing temperature could not exceed the maximum on 12 August (Fig. 6, bottom left). The overall precipitation sum had a maximum in the case where temperature was increased the most. Changes in temperature by about ±1 K had only a minor effect on the amount of precipitation (Fig. 6, bottom right).

b. Case 2: Flood event in January 2003, type W1

1) SYNOPTIC SITUATION

At the end of December 2002 and in the first days of January 2003 there were repeated heavy precipitation events in Germany and other countries of central Europe. The weather conditions were characterized by the presence of two different air masses: cold continental air in the north and east and mild maritime air in the south and southwest. In that region of a pronounced contrast of the air masses, large amounts of precipitation advanced from the southwest on 21 December. During the period between 23 and 28 December, only little, localized, precipitation occurred. After that, long-lasting precipitation started again from the southwest, associated with troughs, until the first days of January 2003. The daily precipitation sums exceeded 40 mm at some stations. Accumulated precipitation from 20 December to 6 January exceeded 100 mm over large areas. Because of the saturated soil as a result of the preceding precipitation, the heavy and long-lasting precipitation with a persistent westerly flow [Winkelförmige Westlage (WW), maritime westerly; and Westlage zyklonal (WZ), cyclonic westerly] led to flooding of numerous rivers, including tributaries of the Elbe River. However, the precipitation amounts were smaller and did not assume such alarming proportions as during the flood event in August 2002.
2) VALIDATION

For the winter event in 2002/03, the model simulations were started at 0000 UTC 21 December 2002 and ended at 0600 UTC 5 January 2003. The first 6 h were not taken into account for the evaluation, so the model results were available for 15 days. The precipitation sum for the overall period is shown in Fig. 7. The intensity was overestimated by the model, but the spatial agreement was quite good and the maxima in the Ore Mountains and in the Bohemian Forest matched the observations. In the northwestern part of the catchment area, the model produced more precipitation than in the southeastern part. This can be found in the observations as well. Despite the overestimation of the precipitation maximum over the Ore Mountains of about 50 mm, the model simulation had quite a high correlation coefficient of 0.76. The model could reproduce the three distinct maxima quite well, with the maxima on 30 December and 2 January being slightly overestimated. Similar to the August 2002 case, the 2.8-km resolution reduced all maxima, without improving agreement with observations. We, therefore, did not consider further these high-resolution results.

3) SHIFTING AGAINST OROGRAPHY

Except for scenario n2, the scenarios did not result in noticeable changes in precipitation with respect to the reference run. Scenario n2 missed high precipitation maxima at some grid points, therefore lowering the local maximum on 30 December (Fig. 8, left). For the others, the shifting of the general weather situation had no significant effect on the precipitation intensity. For the scenarios, changes in average precipitation with respect to the reference run were around ±5 mm per grid point (Fig. 8, right), which is considerably smaller (about one fourth) than the amount of the summer event in 2002 with the same shift (Fig. 5, right). The spatial distribution of the precipitation pattern was nearly identical to the
precipitation pattern of the reference run in all cases. This relatively low sensitivity of the winter 2003 case, especially in comparison with the summer 2002 case, can mainly be explained by the more homogeneous, low-gradient synoptic weather conditions, where airmass properties over the Elbe catchment area are much less affected by the pattern shifting.

4) Modified Temperature and Humidity Fields

The scenarios with modified relative humidity showed a distinct sensitivity on 29 and 30 December 2002 and to a minor degree on 2 January 2003 (Fig. 9, left). The modifications had no effect on precipitation during the other simulated days. While the decrease of the precipitation sum was clearly visible when relative humidity was decreasing, the precipitation sum did not change by increasing relative humidity. The changes in specific humidity based on changes in temperature had no effect on the precipitation sum (Fig. 9, right), and the spatial distribution was not changed. This synoptic situation could be identified as being quite insensitive to changes in temperature, so forecasts for such situations might be considered more certain.

5. Conclusions and outlook

The low resolution of large-scale weather forecast models implies some uncertainty of the position of
weather systems, entailing a range of forecasted precipitation amounts by regional forecast models, especially over complex terrain. The width of this range depends on the synoptic situation and can lead in some cases to overestimation and, more importantly, underestimation of extreme precipitation events. We presented two simple methods to estimate this range: 1) a shift of the synoptic systems relative to the underlying orography and 2) modification of airmass properties within physically reasonable limits. For the simulations, the COSMO model of the German Weather Service was used. A validation exercise showed that the model is capable of simulating two typical extreme precipitation events with different history in a satisfactory way, without modifying the operational setup.

For the summer 2002 event, which is an example of convective weather conditions with strong large-scale gradients, shifting caused noticeable changes in the precipitation pattern and amount. Our results indicate that the precipitation that occurred during this event was “average extreme” within a range of about ±25 mm as a gridpoint average. Precipitation increases markedly when the large-scale weather patterns are shifted to the north or to the west.

For more homogeneous synoptic situations, as in winter 2002/03, the shift did not lead to advection of different air masses into the catchment area; therefore, the range of gridpoint averages of precipitation was considerably smaller than for summer 2002.

Similar results were obtained for the modification of airmass properties. Whereas the convective event in summer 2002 showed a high sensitivity against changes in specific humidity, the more homogeneous event was closer to saturation and, therefore, less sensitive to changes in relative humidity and temperature.

The methods described here are not limited to the COSMO model. They can be easily applied to other models and other boundary data because no changes in the source code of the models are necessary. They could complement operational weather forecasts in the run-up of potentially extreme events to obtain a “small ensemble” estimate of the range, or they can complement existing forecast ensembles. For extreme precipitation climatologies (and possibly also variables other than precipitation), such methods could help to put extreme value statistics on a broader basis and also to classify weather conditions according to their precipitation potential, and they could provide a simple way to improve estimates of extreme precipitation under a changing climate.

The simulations are presently used to drive hydrological models for coupled scenario simulations of extreme events to evaluate the hazard potential for a 60-km stretch of the Elbe River; first results show that the discharge at gauges in the middle Elbe basin increases considerably when north- and west-shifted precipitation fields are used.

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